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AUTHOR(S):

Lee, Seung Joo

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Dimensional Crossovers of Electrons and a Low Dimensional Electron Gas with Tilted Magnetic Fields

Seung Joo Lee

Department of Physics, Korea Military Academy

Seoul, 139-799, Korea

Recent advances in layered-structure-fabrication technology have reached a level, where it is now possible to fabricate structures with extremely small dimensions, comparable to the de Broglie wavelength(λ_D) of the electron in one or more of the three cartesian directions. Among them devices based on Q1D electron wires (or quantum wires), in which electrons are confined in two directions, are also considered [1]. Quantum wires and quantum boxes (or Q0D electron gas systems) with three-dimensionally confined electrons constitute a considerable part of recent semiconductor research[2]. To study the transport properties of these systems, one should investigate the density of states (DOS) carefully, because the change in the density of states affects directly the electrical transport properties of these structures as a result of reduced dimensionality.

The DOS of a low dimensional electron gas (LDEG) in the presence of magnetic field has been discussed in many literatures measuring the magnetocapacitance[3,4]. Furthermore an electrical confinement which is usually controlled by (alternate) gate voltage [5] and, so called the illumination method[6] are used to get a LDEG. The etched silicon filaments also discussed recently as quantum wires or quantum dots [7]. But the DOS of a LDEG of confined electrons in small space which is constructed by reducing the size of the confinement is not discussed frequently, see ref.1. A typical example of an ideal system having Q0D character is that of electron confined in a quantum box

with impenetrable potential barriers. Despite of the large number of studies on quantum wire and quantum box structures up to date, we have not found researches on the cross-sectional local density of states of the quantum wire structure, that of the quantum box structure, and the crossover of the DOS from a three dimensional DOS to a quasi-zero dimensional DOS.

To illustrate the formation of a quasi-one-dimensional electron gas (Q1DEG) using the classical electrostatic method, a simple metal-insulator-semiconductor (MIS) structure with very many parallel gate electrodes has been treated by making use of the conformal mapping method. We actually try to confine the electrons which is originally confined in the x-z plane in the z-direction as well to form a Q1DEG system. This is shown in figure 1.

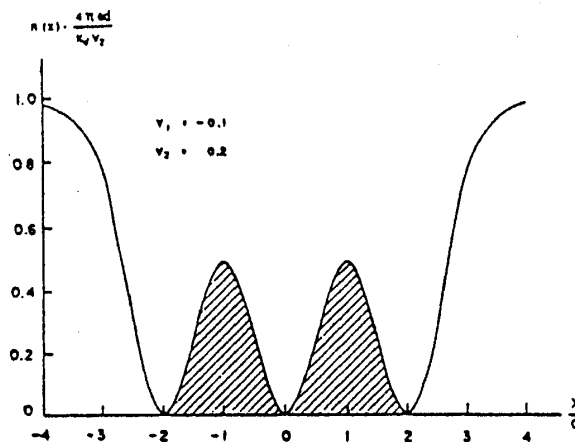


Fig.1. The surface charge density vs. position.

We consider a rather artificial quantum box structure, so called the three directional double-barrier resonant-tunneling structures(DBRTS) to study quantum mechanically. The eigenfunctions and eigenvalues are evaluated from an effective mass Schrödinger equation. Using these results, we have calculated the local density of states and the global density of states. The crossovers of the DOS is calculated. Especially, we reveal the crossovers of the DOS from 3D to QOD. Among them we show here the crossover from 2D to 1D in Fig 2.

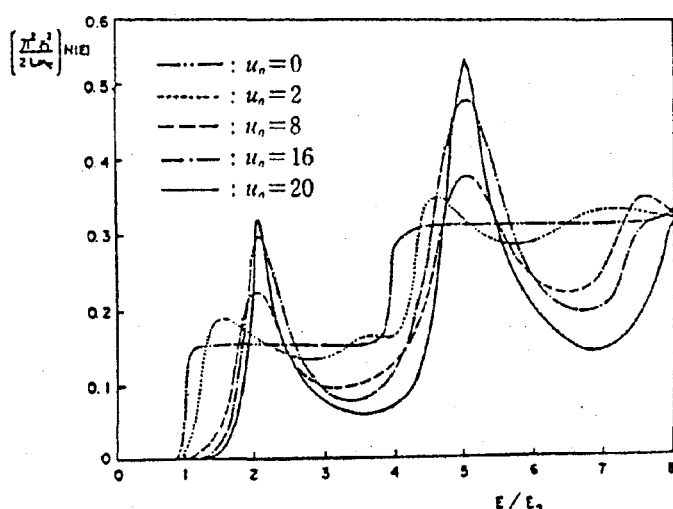


Fig.2. Crossover of the global DOS from 2D to 1D.

Now we consider the LDEG in the presence of a tilted magnetic field. Application of a strong magnetic field to a confined electron system has a pronounced effects on spatial quantization. However most of the theoretical and experimental work regarding these systems is concerned with the configuration in which the magnetic field is perpendicular or parallel to interfaces[8] in which electrons or holes are confined.

In this work we deal with a less frequently investigated configuration where an external magnetic field is tilted to the gradient of confining potential with a parabolic and a triangular shapes. It was using this system that Fang and Stiles[9] performed an ingenious experiment in 1968 to obtain the effective Lande g-factor using the fact that the Landau splitting depends upon the normal component of the magnetic field and the spin splitting due to the total field. The relative magnitude of those splittings vary with the tilt angles. To explain this experiment many theoretical works have followed. Among them, Ando and Uemura[10] has explained the experiment as the exchange effect among electrons in the Landau level. Many experiments have been performed for different ranges of tilt angles and material[11] and most of the works have been done by studying quantum oscillations in SdH measurements.

Marx and Kümmel[8] showed that the magnetization parallel to the layer

interfaces exhibits oscillations and sharp jumps as a function of the chemical potential. In the GaAlAs-GaAs system, it is not easy to alter the chemical potential with one sample. Motivated by this fact, we have investigated this problem with a triangular well which can be approximated as a potential profile in a Si MOS inversion layer and a parabolic well with which we can decouple the Hamiltonian.

We begin by solving the Schrödinger equation for the parabolic quantum well system which can be decoupled[12] and shows the importance of the coupling term in calculation of magnetization but not in energy. The calculation is devoted to an asymmetric triangular well as well by making use of the perturbation method. Oscillating magnetization is calculated and is given in Fig 3.

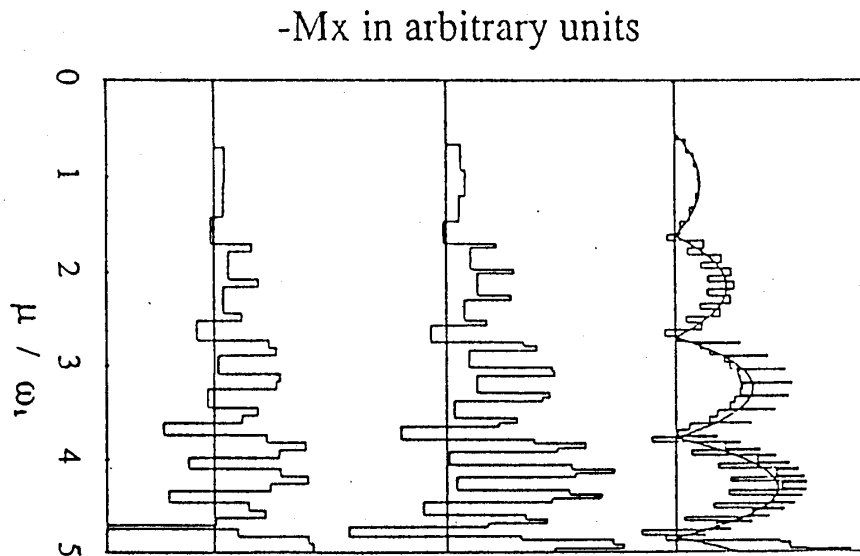


Fig.3. $-M_x$ vs. μ at various tilt angles for the quasi-2DEG ($\omega_c = 0.4\omega_1$ is used). : the top graph shows the $\theta = 0$ (smooth) and $\theta = 22.5^\circ$ cases superimposed ; the middle graph, the $\theta = 45^\circ$ case ; and the bottom graph, the $\theta = 67.5^\circ$ case. Horizontal lines represent $M_x = 0$.

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